INSTRUMENT UNCERTAINTY EFFECT ON CALCULATION OF ABSOLUTE HUMIDITY USING DEWPOINT, WET-BULB, AND RELATIVE HUMIDITY SENSORS

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ABSTRACT

As part of the U.S. Department of Energy's Advanced Desiccant Technology Program, the National Renewable Energy Laboratory (NREL) is characterizing the state-of-the-art in desiccant dehumidifiers, the key component of desiccant cooling systems. The experimental data will provide industry and end users with independent performance evaluation and help researchers assess the energy savings potential of the technology. Accurate determination of humidity ratio is critical to this work and an understanding of the capabilities of the available instrumentation is central to its proper application. This paper compares the minimum theoretical random error in humidity ratio calculation for three common measurement methods to give a sense of the relative maximum accuracy possible for each method assuming systematic errors can be made negligible. A series of experiments conducted also illustrate the capabilities of relative humidity sensors as compared to dewpoint sensors in measuring the grain depression of desiccant dehumidifiers. These tests support the results of the uncertainty analysis. At generally available instrument accuracies, uncertainty in calculated humidity ratio for dewpoint sensors is determined to be constant at approximately 2%. Wet-bulb sensors range between 2% and 6% above 10 g/kg (4%-15% below), and relative humidity sensors vary between 4% above 90% rh and 15% at 20% rh. Below 20% rh, uncertainty for rh sensors increases dramatically. Highest currently attainable accuracies bring dewpoint instruments down to 1% uncertainty, wet-bulb to a range of 1%-3% above 10 g/kg (1.5%-8% below), and rh sensors between 1% and 5%.

NOMENCLATURE

p	total pressure	kPa
p_v	partial pressure of water vapor	kPa
rh, Φ	relative humidity	%, decimal rh
t	dry-bulb temperature	°C
T	absolute temperature	K
t^*	thermodynamic wet-bulb temperature	°C
w	absolute humidity ratio	$kg_{vapor}/kg_{dry\ air}$

SUBSCRIPTS

da	dry air
dp	dewpoint or dewpoint approach
rh	relative humidity approach
std	standard psychrometric conditions
v	water vapor
vs	water vapor over saturated water
wa	wet air
wb	wet-bulb approach

INTRODUCTION

In 1995 about 3.8 EJ (3.6 quads) of primary energy were used to air condition buildings (BTS Core Data Book, 1997). This energy end use is expected to increase as the population shifts to the warmer southern states (Pesaran, 1992). This presents the air-conditioning industry with several challenges. Among these are demands for increased energy efficiency and ventilation requirements, improved indoor air quality and comfort, phase-out of chlorofluorocarbons (CFCs), and a growing concern over environmental controls and rising peak-demand charges. New approaches to air-conditioning are being evaluated to resolve these economic, environmental, and regulatory issues.

The desiccant cooling and dehumidification technology has important advantages that can help solve many of today's issues. The latent and sensible loads are handled more efficiently than in vapor compression cooling equipment because the components are optimized to independently remove these separate loads. Recent advances in sorptive materials over conventional silica gel and dehumidifier design innovations are making the technology increasingly attractive. As a result, the use of desiccant cooling and dehumidification systems for building comfort conditioning has increased steadily during the past several years.

As the public eye turns towards these products, field test and certification data are increasingly needed to highlight their unique humidity control capabilities. Accurate humidity measurement is therefore crucial to these studies and is commonly accomplished by one of three methods. Historically, heating, ventilation, and air-conditioning (HVAC) test labs have measured wet-bulb, dry-bulb, and pressure to use in calculating humidity. In field testing, relative humidity sensors are often employed along with dry-bulb and ambient pressure measurements to determine psychrometric conditions. The third broadly available measurement technique, often used in laboratories and industrial process control, involves the dewpoint temperature and pressure.

Advanced Desiccant Technology Program

In 1995, a national program was established to assist industry in accelerating the integration of desiccant cooling technologies into broad building air-conditioning markets where their full energy savings and potential to enhance indoor air quality can be realized. National laboratories are working with desiccant system manufacturers and HVAC equipment manufacturers to reach this goal. Desiccant equipment manufacturers are teaming with HVAC manufacturers to develop, market, and implement the next generation of this technology. NREL is conducting baseline performance testing and developing figures of merit to concisely summarize this data. Broad performance maps developed through this testing program will also allow designers to quickly evaluate HVAC system flexibilities provided by recent desiccant material and wheel design improvements.

To this end, we have obtained several desiccant dehumidifier wheels from a number of major desiccant equipment manufacturers and suppliers. These wheels are being tested in accordance with the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) proposed National Standard 139P (1995). Gross moisture removal capacity (MRC) is the primary rating figure calculated as the product of process air mass flow rate and the absolute humidity depression across the dehumidifier.

EXPERIMENTAL APPARATI

Descriptions of many humidity measurement options can be found in references *ASHRAE Handbook of Fundamentals* (1997*), The Dehumidification Handbook* (1990*), ASHRAE Brochure on Psychrometry* (1977), and *ANSI/ASHRAE Standard* 41.6-94 (1994). The following points can be found in some or all of these resources:

- Wet-bulb temperatures are typically obtained by providing a 3.5-5 m/s (700-1000 fpm) airflow over a thermometer, thermocouple, or resistance temperature devices (RTD) wrapped in a wick that is constantly supplied with just enough water to saturate the immediately adjacent sample air.
- Relative humidity is electronically measured directly by several methods. For example, electronic capacitance devices use humidity-dependent changes in the resistance of a dielectric material exposed to the sample air.
- Dewpoint temperatures are typically determined with a chilled mirror where an RTD measures the mirror surface temperature at the moment condensation is detected at that surface.

All humidity measurements are subject to common sources of systematic error related to the sampled airstream, which can involve duct stratification and condensation prior to the sensor. Good experimental practices must be observed to avoid causing such problems with the sample air. Typical errors can be of sufficient magnitude to dominate the uncertainty analysis presented here. Detailed lists of caveats for wet-bulb and dewpoint systems in particular are provided in ANSI/ASHRAE Std. 41.6-94 (1994).

NREL’s Advanced HVAC Test Facility was built to test a range of equipment, including dehumidifiers, heat exchangers, and heat pipes. The facility will test any device that requires two independently monitored and controlled airstreams at design flow rates of 0.06-1.4 kg/s (100-2500 scfm), temperatures below freezing to over 205°C (401°F), and humidities 2.8-40 g/kg (20-280 gr/lb). A complete description of the system is provided in Slayzak et al. (1996). A description of our measurement station design for minimizing air sampling bias errors follows.

Each inlet and outlet measurement station consists of a cross of 6 mm (1/4”) tubing that samples air from several points along two of the duct’s diameters for spatially averaged humidity readings. Each cross also supports several type-T thermocouples for dry-bulb temperature measurement with absolute accuracy of ±0.20°C (0.36°F). A combination of turbulent development length, baffles, and plenums enhance the mixed condition at these stations. Infrared imaging shows a temperature variation of less than 1°C (33.8°F) under typical operating conditions. Humidity profiles are assumed similar. Air samples are continuously pumped from the measurement stations at the rate of 0.7 L/min (1.5 CFH) through a National Institute of Standards and Technology-traceable, calibrated model SIM-12H General Eastern chilled-mirror hygrometer with a dewpoint accuracy in the range of interest of ±0.15°C (0.27°F). Stainless steel sampling tubes that lead from the measurement stations to the hygrometers prevent moisture exchange with the tube walls. These tubes are wrapped with variable output heat tape and insulation to ensure that condensation does not occur through heat exchange with laboratory ambient temperature prior to the humidity sensor. When dewpoint temperature nears ambient temperature, the sensor body itself is heated and its temperature self-regulated.

For the experimental portion of this paper, each process air inlet and outlet has also been instrumented with a pair of relative humidity transmitters to compare their measurements with those of the dewpoint hygrometers. Each pair includes a transmitter with ±1% rh, ±0.2°C accuracy (Vaisala HMP 233) and ±3% rh, ±0.3°C accuracy (Vaisala HMD 50Y). The sensors are placed at the center of the duct’s cross section, at least 3 m (10 ft) downstream of the wheel to ensure highly mixed air.

UNCERTAINTY ANALYSIS METHOD

The root sum square method of uncertainty calculation is applied here to the individual equations used in calculating humidity ratio for each experimental approach. It is well documented as the preferred method for the independent measurements of temperatures, humidities, and pressures examined here (Kline and McClintock, 1953; Abernethy and Ringhiser, 1985; Dieck, 1992; Carotenuto et al., 1995). Rather than sum the individual contributions of each measurement to obtain a true uncertainty, the method argues that because they are independent, it is statistically likely that the errors will partially counteract each other most of the time such that the square root of the sum of the squares of the individual uncertainties is a more representative gauge of the overall random uncertainty.

The dewpoint approach uses the following equation to obtain humidity ratio (ASHRAE Handbook of Fundamentals, 1997):

$$w = \frac{0.622 \cdot p_v}{p - p_v} \tag{1}$$

where p_v is p_{vs} evaluated at the dewpoint:

$$p_v = p_{vs}(T_{dp}) = \exp\begin{pmatrix} \frac{C_8}{T_{dp}} + C_9 + C_{10}T_{dp} + C_{11}T_{dp}^{\ 2} \ldots \\ \ldots + C_{12}T_{dp}^{\ 3} + C_{13}\ln(T_{dp}) \end{pmatrix} \tag{2}$$

for dewpoints between 0°C and 100°C. The coefficients C_8 - C_{13} are found in the ASHRAE Handbook of Fundamentals (1997). A similar equation is used for dewpoints between -100°C and 0°C and is found in the *ASHRAE Handbook of Fundamentals* (1997) as well. Applying the root sum square method, the random uncertainty is expressed in units of kg_v/kg_{da} as:

$$\delta w_{dp} = \left[\left(\frac{\partial w}{\partial t_{dp}}\delta t_{dp}\right)^2 + \left(\frac{\partial w}{\partial p}\delta p\right)^2\right]^{1/2} \tag{3}$$

where δt_{dp} and δp are the instrument uncertainties in °C and kPa respectively. The partial derivatives can be interpreted as sensitivity coefficients of the humidity ratio result to each of the measured parameters and are given by Eqs. (4) and (6):

$$\frac{\partial w}{\partial t_{dp}} = 0.622\left(\frac{\partial p_v}{\partial t_{dp}}\right)\left[\frac{p}{(p - p_v)^2}\right] \tag{4}$$

where

$$\frac{\partial p_v}{\partial t_{dp}} = p_v\left(\frac{-C_8}{T_{dp}^{\ 2}} + C_{10} + 2 \cdot C_{11} \cdot T_{dp} + 3 \cdot C_{12} \cdot T_{dp}^2 + \frac{C_{13}}{T_{dp}}\right) \tag{5}$$

$$\frac{\partial w}{\partial p} = \frac{-0.622 \cdot p_v}{(p - p_v)^2} \tag{6}$$

The wet-bulb approach uses this equation for calculating humidity ratio:

$$w = \frac{(K_1 - K_2 t^*)w_s^* - (t - t^*)}{K_1 + K_3 t - K_4 t^*} \tag{7}$$

where the constants K_1 - K_4 are found implicitly in *ASHRAE Handbook of Fundamentals* (1997) and w_s^* is the humidity ratio at the thermodynamic wet-bulb temperature, t^* ,which is approximated by using the wet-bulb temperature in its place. So,

$$w_s^* = \frac{0.622 \cdot p_{vs}^*}{p - p_{vs}^*} \tag{8}$$

where p_{vs}^* is the vapor pressure of water, Eq. (2) evaluated at the wet-bulb temperature, t^* in °K. Random uncertainty is then:

$$\delta w_{wb} = \left[\left(\frac{\partial w}{\partial t}\delta t\right)^2 + \left(\frac{\partial w}{\partial t^*}\delta t^*\right)^2 + \left(\frac{\partial w}{\partial p}\delta p\right)^2\right]^{1/2} \tag{9}$$

Again the partial derivatives are interpreted as the sensitivity coefficients and are given in Eqs. (10), (11) and (14):

$$\frac{\partial w}{\partial t} = w_s^*(4514 - 4.3 \cdot t^*) + 5.991 \cdot t^* - 3.61 \cdot t - 2501 \tag{10}$$

$$\frac{\partial w}{\partial t^*} = \begin{Bmatrix} K_4\left[\frac{(K_1 - K_2 \cdot t^*)w_s^* - (t - t^*)}{(K_1 + K_3 \cdot t - K_4 \cdot t^*)^2}\right] \ldots \\ \ldots + \frac{(K_1 - K_2 \cdot t^*)\left(\frac{\partial w_s^*}{\partial t^*}\right) - K_2 \cdot w_s^* + 1}{K_1 + K_3 \cdot t - K_4 \cdot t^*} \end{Bmatrix} \tag{11}$$

where

$$\frac{\partial w_s^*}{\partial t^*} = 0.622\left(\frac{\partial p_{vs}^*}{\partial t^*}\right)\left[\frac{p}{(p - p_{vs}^*)^2}\right] \tag{12}$$

and

$$\frac{\partial p_{vs}^*}{\partial t^*} = p_{vs}^*\left(\frac{-C_8}{T^{*2}} + C_{10} + 2 \cdot C_{11} \cdot T^* + 3 \cdot C_{12} \cdot T^{*2} + \frac{C_{13}}{T^*}\right) \tag{13}$$

$$\frac{\partial w}{\partial p} = \frac{-0.622 \cdot p_{ws}^*(K_1 - K_2 \cdot t^*)}{(p - p_{ws}^*)^2(K_1 + K_3 \cdot t - K_4 \cdot t^*)} \tag{14}$$

For the relative humidity approach, similarly:

$$w = \frac{0.622 \cdot p_v}{p - p_v} \tag{15}$$

where

$$p_v = \Phi \cdot p_{vs} \tag{16}$$

where p_{vs} is Eq. (2) evaluated at the dry-bulb temperature, and Φ is the decimal representation of relative humidity. Random uncertainty is then likewise:

$$\delta w_{rh} = \left[\left(\frac{\partial w}{\partial t} \delta t \right)^2 + \left(\frac{\partial w}{\partial \Phi} \delta \Phi \right)^2 + \left(\frac{\partial w}{\partial p} \delta p \right)^2 \right]^{1/2} \tag{17}$$

where

$$\frac{\partial w}{\partial t} = 0.622 \left(\frac{\partial p_v}{\partial t} \right) \left[\frac{p}{(p - p_v)^2} \right] \tag{18}$$

and

$$\frac{\partial p_v}{\partial t} = p_v \left(\frac{-C_8}{T^2} + C_{10} + 2 \cdot C_{11} \cdot T + 3 \cdot C_{12} \cdot T^2 + \frac{C_{13}}{T} \right) \tag{19}$$

The remaining sensitivity coefficients are:

$$\frac{\partial w}{\partial \phi} = 0.622 \cdot p_{vs} \left[\frac{p}{(p - p_v)^2} \right] \tag{20}$$

$$\frac{\partial w}{\partial p} = \frac{-0.622 \cdot p_v}{(p - p_v)^2} \tag{21}$$

RESULTS AND DISCUSSION

Here we provide the results of the uncertainty analysis detailed in the previous section. Experimental results from a series of tests comparing absolute humidity calculations from dewpoint sensor and relative humidity sensor measurements are also provided.

Uncertainty Results

The solutions to Eqs. 2, 5 and 8 are presented in Fig. 1 for typically achievable instrument accuracies given as "Standard Accuracy" instruments in Table 1. It is clear that the dewpoint approach incurs the least amount of uncertainty in absolute humidity. The value is nearly constant at approximately 2% over the entire range of terrestrial humidity ratios. The uncertainty incurred by the relative humidity approach is quite low for high relative humidities (~5%) but becomes fairly large below 35% rh. As shown later by our experiments, this characteristic of the rh approach is a hurdle that must be addressed when testing desiccant dehumidifiers. This is to be expected since the uncertainty of these instruments is expressed in units of rh. As the relative humidity decreases, this uncertainty becomes a larger and larger portion of the measured value. Investigating the analysis for the wet-bulb approach reveals large uncertainties are possible below 4 g/kg (28 gr/lb) at moderate wet-bulb temperatures. Only at very dry process inlet conditions, however, or very high grain depressions would this be a concern for desiccant wheel testing.

Table 1 Typical Uncertainties for Standard and High Accuracy Instruments

	Temperatures (t, t_{dp}, t^*)	Relative Humidity	Pressure
Standard Accuracy	±0.3°C	±3% rh	±0.13 kPa
High Accuracy	±0.15°C	±1% rh (0-90% rh) ±2% rh (90-100% rh)	±0.13 kPa

Figure 2 again depicts the solutions to Eqs. 2, 5, and 8; however, for a more direct comparison, results for the relative humidity approach are also depicted at constant wet-bulb temperature. In this figure, traveling to the left along a line of constant wet-bulb temperature decreases the relative humidity, thus increasing the uncertainty in absolute humidity for the rh approach. The dewpoint approach produces the same results as in the previous figure, independent of wet-bulb temperature. Figure 3 likewise directly compares the three approaches with respect to lines of constant relative humidity. For the standard accuracies analyzed here, this figure makes it clear that the wet-bulb approach is generally more robust than the rh approach. Although, it should be noted that some of the points presented in this figure require wet-bulb depressions so large that they are not recommended by good wet-bulb procedures.

The relative magnitude of the partial derivative sensitivity coefficients point to the instruments within a particular approach for which outputs are critical in determining absolute humidity. For the instruments listed as standard accuracy in Table 1, the result for the dewpoint approach is typically 15 times more sensitive to dewpoint uncertainty than pressure uncertainty. For the wet-bulb approach, wet-bulb uncertainty typically has a 2-5 times larger effect than dry-bulb and a 15-60 times larger effect than pressure. For the relative humidity approach, rh measurement uncertainty has a 1-100 times larger effect

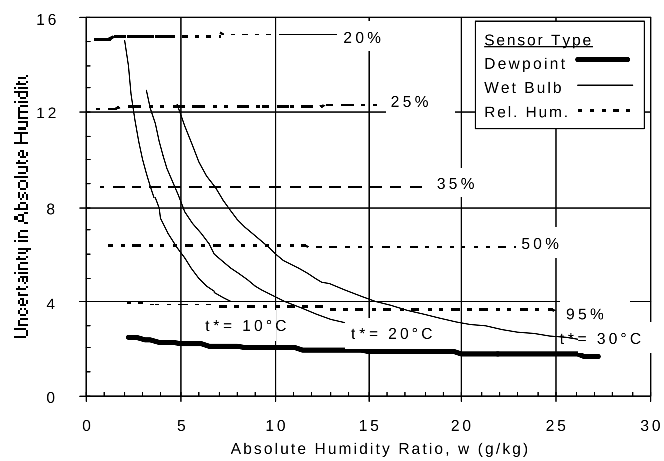

Figure 1. Uncertainty Analysis Results Using "Standard Accuracy" Instrumentation

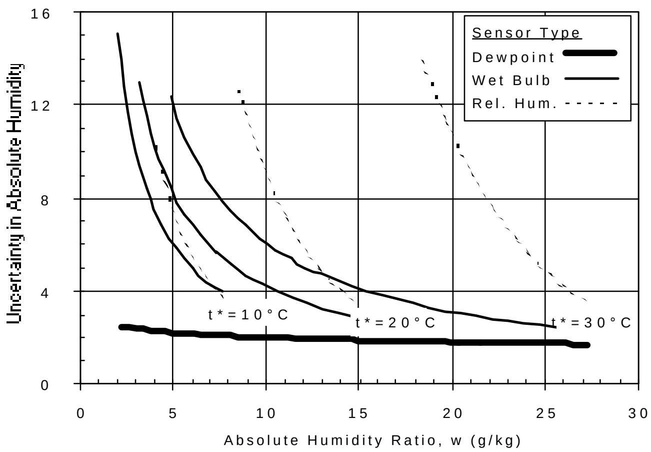

Figure 2. Uncertainty Analysis Results at Constant Wet-bulb Temperatures

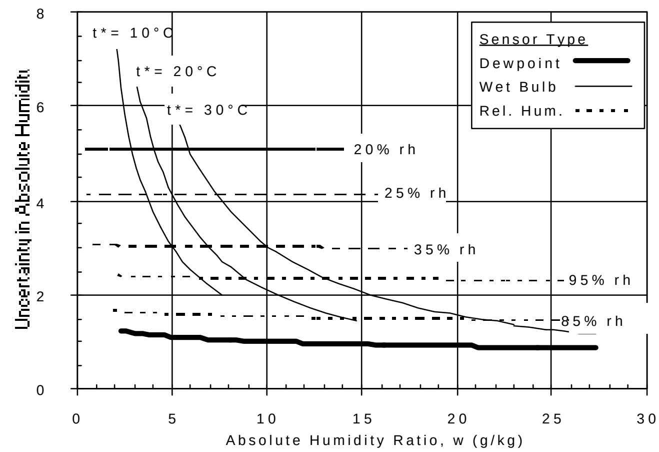

Figure 4. Uncertainty Analysis Results Using "High Accuracy" Instrumentation

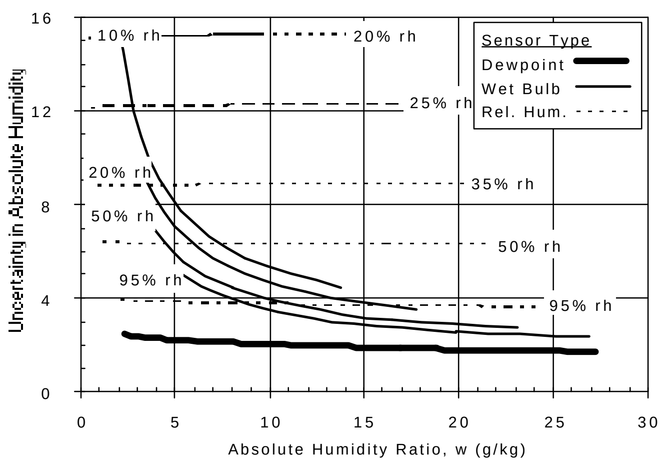

Figure 3. Uncertainty Analysis Results at Constant Relative Humidities

than dry-bulb and a 20-150 times larger effect than pressure. The accuracy of the rh sensor has the largest effect on uncertainty at lower relative humidities.

Figure 4 illustrates the effect of increased instrumentation accuracies, identified as "High Accuracy" instruments in Table 1. This level of sensor accuracy is only achievable with the use of state-of-the-art instrumentation (e.g. high quality RTD for the wet-bulb measurement) and excellent experimental practices. A significant improvement in uncertainty is evident between Fig. 1 and Fig. 4, with uncertainty from the dewpoint and wet-bulb approaches cut in half and that from the relative humidity approach reduced by two-thirds. Because relative humidity sensor performance is discontinuous above 90% rh for the high accuracy models, absolute humidity uncertainty above 90% rh becomes larger than it is for moderate rh conditions.

Experimental Comparison between Dewpoint Sensors and Relative Humidity Sensors

A series of tests were completed at the Advanced HVAC Test Facility that explored the use of relative humidity sensors in calculating the absolute humidity of air entering and leaving a regenerated desiccant dehumidifier. Although the sensors cost and suitability for automation is attractive for application in field-testing, until recently, their accuracies have not been ideal.

Two pairs of relative humidity sensors were tested. One pair has the rh uncertainties listed in Table 1 as "Standard Accuracy" while the other pair has the "High Accuracy" uncertainties. An initial series of tests computed the absolute humidity of a single airstream with each of these four relative humidity sensors along with two state-of-the-art dewpoint hygrometers. Humidity ratio was held at 17±0.3 g/kg while the dry-bulb temperature was incrementally raised to vary relative humidity between 15 minute steady-state periods. For each pair of sensors, the difference between their computed values is insignificant and the difference between the pairs varied from 2% to 15% (Fig. 5). This clearly shows a high precision for all the instruments and agreement within their respective accuracies. Error bars are shown only for the high accuracy rh sensors for readability purposes. The bars for the dewpoint sensors would be at approximately 1.3% and those for the standard accuracy rh sensors would range from 4% at high relative humidity to 21% at low rh.

An additional series of tests are used to illustrate the uncertainties encountered when using these instruments to compare the difference in absolute humidity between two airstreams. For these tests, the pairs are split so one sensor from each pair is upstream and the other downstream of a desiccant dehumidifier. Isothermal air (±0.2 °C) with a constant absolute humidity (±0.3 g/kg) is processed by the dehumidifier until steady-state conditions are met for at least 15 minutes. The inlet and outlet humidity ratios are computed for each measurement approach and averaged over this steady-state period. For these tests, process inlet air relative humidities of 30%, 50% and 70% are achieved while holding temperature constant and varying humidity ratio. The results are given in Fig. 6. Due to the heat of adsorption and

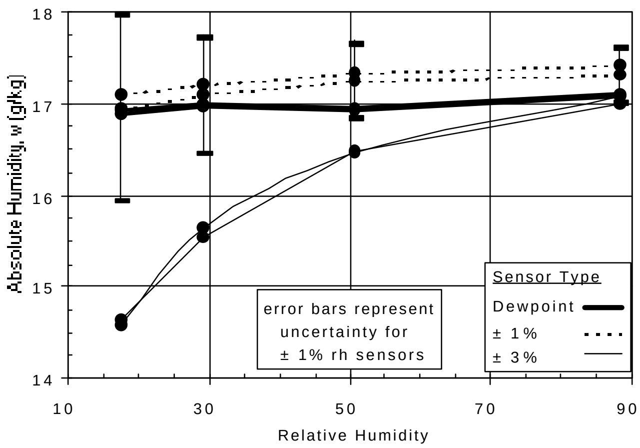

Figure 5. Humidity Measurements of Air with Constant Absolute Humidity

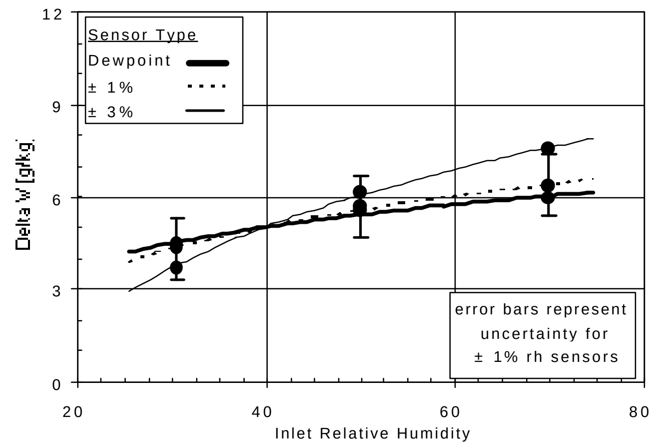

Figure 7. Humidity Depression of Process Air Across a Desiccant Dehumidifier

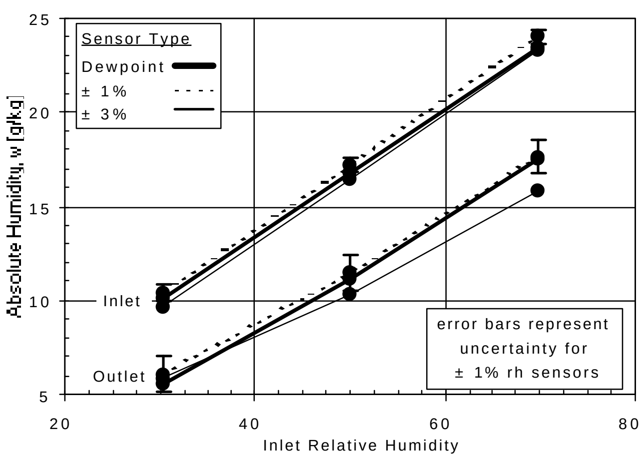

Figure 6. Humidity Measurements at the Inlet and Outlet of a Desiccant Dehumidifier

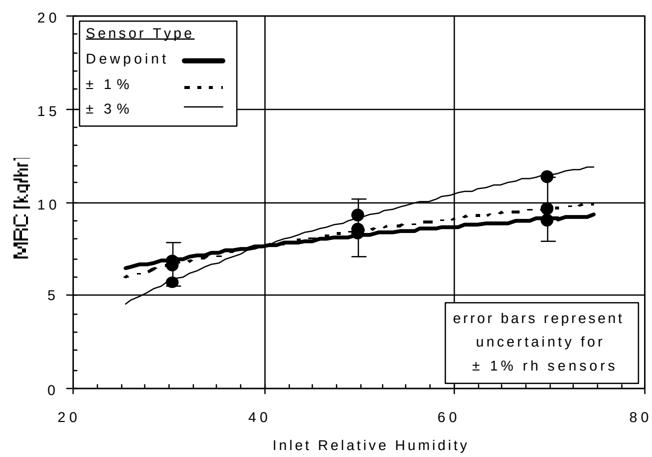

Figure 8. Moisture Removal Capacity (MRC) of a Desiccant Dehumidifier

heat carryover from the regeneration airstream, the outlet air is not only drier but about 20°C warmer than the inlet, giving the outlet air a low relative humidity (~10%-15%). Again, error bars are shown only for the high accuracy rh sensors.

Figure 7 shows the absolute humidity depressions (Δw) calculated from the data in Fig. 6. The uncertainty in Δw ($\delta\Delta w$) is calculated using the root sum square method:

$$\delta\Delta w = \left[\left(\frac{\partial \Delta w}{\partial w_{in}}\delta w_{in}\right)^2 + \left(\frac{\partial \Delta w}{\partial w_{out}}\delta w_{out}\right)^2\right] \tag{22}$$

and is illustrated as error bars in Fig. 7 for the high accuracy rh sensors. The accuracy of the ±3% rh sensors translate into unacceptable (40%-70%) uncertainty in Δw. The dewpoint approach yields a 3%-5% uncertainty under the same conditions.

The MRC is the standard figure of merit for rating dehumidifiers and is calculated by:

$$MRC = \dot{m}\left(w_{in} - w_{out}\right) = \dot{m}\cdot\Delta w \tag{23}$$

where $\dot{m}$ is the process air mass flow rate, w_{in} is the inlet absolute humidity and w_{out} is the outlet absolute humidity. Applying the root sum square method to Eq. (23) gives the uncertainty in MRC (δMRC) as:

$$\delta MRC = \left[\left(\frac{\partial MRC}{\partial \dot{m}}\delta\dot{m}\right)^2 + \left(\frac{\partial MRC}{\partial \Delta w}\delta\Delta w\right)^2\right]^{1/2} \tag{24}$$

where $\delta\dot{m}$ is the uncertainty in the mass flow rate measurement (approximately ±3% of measurement for these experiments) and $\delta\Delta w$ is the uncertainty in Δw calculated with Eq. (22). Again the uncertainty in MRC is illustrated as error bars in Fig. 8 for the 1% rh sensors. Compared to $\delta\Delta w$ results, the addition of flow uncertainty has a small effect on the dewpoint approach, raising the random uncertainty to 4%-6%, and has a negligible effect on the calculated uncertainty for the 3% rh sensors.

CONCLUSIONS

The root sum square method of uncertainty calculation is applied to the determination of absolute humidity ratio using dewpoint, wet-bulb, and relative humidity measurement approaches. Only instrument uncertainty is considered here to assess the relative robustness of these three common techniques. Generally available instrument accuracies are compared to the highest currently achievable through state-of-the-art devices and practices.

Examination of the sensitivity coefficients for each approach shows dewpoint temperature to be one to two orders of magnitude more important than pressure in determining absolute humidity. Wet-bulb accuracy is only slightly more important than dry-bulb accuracy and both are one order of magnitude more important than pressure determination for this approach. Relative humidity measurements are only slightly more important than dry-bulb for HVAC applications. Their accuracies increasingly dominate uncertainty as both relative and absolute humidities decline.

The results point to the dewpoint approach as the most robust overall. Wet-bulb and relative humidity approaches always incur higher uncertainties and will surpass one another, depending on psychrometric conditions. The analysis indicates that, for the "standard accuracies," the wet-bulb approach is slightly superior at moderate to high wet-bulb conditions and at very low rh. Relative humidity sensors provide a slight performance edge in the far left region of the psychrometric chart where lines of constant rh are compressed. The results also indicate that the relative humidity approach makes the largest gains in improved uncertainty when advancing from generally available equipment to state-of-the-art. For the "high accuracy" cases, the relative humidity approach gains an advantage in the 70%-90% rh range up through moderate wet-bulb temperatures.

Experiments are conducted to compare the uncertainty in calculated grain depression resulting from relative humidity and dewpoint measurement approaches, specifically as applied to testing regenerated desiccant dehumidifiers. At a nominal humidity ratio depression of 5.5 g/kg (39 gr/lb), state-of-the-art dewpoint sensors exhibit the least amount of uncertainty in Δw (~±4%), and premium relative humidity transmitters encounter only moderate levels of uncertainty (~±18%) and agree with the dewpoint sensors to within ~±7%. Relative humidity sensors with ±3% rh accuracy are not recommended for this application. We stress that all of these sensors were recently calibrated and that manufacturers' calibration schedules must be strictly observed to minimize the very real effects of instrument drift.

Our results also imply a benefit in installing the downstream relative humidity sensor as far from the wheel as possible for two reasons. First, for optimal mixing, but also to allow cooling through the duct walls (or any heat exchange device integral to the desiccant unit) so that the relative humidity may rise to levels where this instrument's accuracy meets the needs of the testing. Judicious application of this observation could make the relative humidity approach very attractive, particularly in field-testing.

Future work should include experimental comparisons of methods that determine absolute humidity using advanced wet-bulb sensors. Additionally, an investigation should be conducted of the feasibility of determining moisture balance, a demanding experimental task, across a moisture exchange device using both the wet-bulb and relative humidity approaches.

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